“INTEGRATED ENERGY-AWARE SCHEDULING, ECC-BASED AUTHENTICATION, AND DELAY OPTIMIZATION TECHNIQUES FOR HETEROGENEOUS IOT SYSTEMS”

A

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TABLE OF CONTENT

1.	**TITLE OF THE THESIS**	**01**
2.	**INTRODUCTION**	**01**
3.	**LITERATURE REVIEW**	**04**
4.	**OBJECTIVE (S) /NEED OF THE STUDY**	**13**
5.	**PROPOSED METHODOLOGY**	**14**
6.	**EXPECTED OUTCOMES**	**15**
7.	**REFERENCES**	**17**

ABSTRACT

The rapid growth of heterogeneous Internet of Things (IoT) systems has introduced significant challenges related to energy consumption, secure communication, and transmission delay due to the diverse nature of connected devices and resource constraints. This work proposes an integrated framework that combines energy-aware scheduling, elliptic curve cryptography (ECC)-based authentication, and delay optimization techniques to enhance the overall efficiency and reliability of heterogeneous IoT environments. An energy-efficient scheduling mechanism is developed to optimize task allocation between IoT devices and gateways, thereby reducing unnecessary power consumption and prolonging network lifetime. To ensure secure and lightweight communication, an ECC-based authentication protocol is designed to provide robust identity verification and secure data transmission with minimal computational overhead suitable for resource-limited IoT nodes.

In addition, an energy-efficient secure identity authentication scheme is introduced to preserve data privacy while minimizing cryptographic energy cost during communication. To address latency issues, optimized queuing and clustering techniques are incorporated to reduce communication delay, improve packet handling efficiency, and support timely data delivery across heterogeneous devices. The proposed unified framework integrates energy management, security mechanisms, and delay reduction strategies into a single architecture, resulting in improved system performance, enhanced scalability, and secure operation for next-generation IoT applications. Experimental analysis is expected to demonstrate that the integrated approach significantly improves energy utilization, authentication efficiency, and communication responsiveness compared to conventional IoT management techniques.

1. INTRODUCTION

Integrated energy-aware scheduling, ECC-based authentication, and delay optimization techniques play a crucial role in enhancing the performance, security, and efficiency of heterogeneous Internet of Things (IoT) systems. These systems consist of diverse devices with varying computational capabilities, energy constraints, and communication requirements. As IoT applications continue to expand across domains such as healthcare, smart cities, industrial automation, and environmental monitoring, the need for efficient resource management and secure communication becomes increasingly significant. This integrated approach addresses three major challenges in IoT systems: energy consumption, data security, and latency.

Energy-aware scheduling focuses on optimizing the use of limited power resources in IoT devices, many of which operate on batteries or energy-harvesting mechanisms. In heterogeneous IoT environments, devices differ in processing power, communication capabilities, and energy availability. Energy-aware scheduling algorithms prioritize tasks based on device energy levels, workload requirements, and network conditions. These algorithms ensure that energy-intensive tasks are assigned to devices with sufficient power while low-energy nodes handle lighter tasks. This approach minimizes unnecessary energy consumption, extends device lifetime, and improves overall system sustainability. Additionally, adaptive scheduling mechanisms dynamically adjust task allocation in response to real-time energy fluctuations, ensuring efficient operation even under varying environmental conditions.

Elliptic Curve Cryptography (ECC)-based authentication provides a robust and lightweight security solution for IoT systems. Due to limited computational resources, traditional cryptographic techniques such as RSA may not be suitable for IoT devices. ECC offers strong security with smaller key sizes, making it ideal for resource-constrained environments. ECC-based authentication ensures secure communication between devices by verifying identities and preventing unauthorized access. It protects sensitive data from threats such as eavesdropping, spoofing, and man-in-the-middle attacks. In heterogeneous IoT systems, where devices frequently communicate across different platforms and networks, ECC-based authentication establishes trust and ensures data integrity. Furthermore, its efficiency reduces computational overhead, conserving energy and improving system performance.

Delay optimization is another critical component in IoT systems, particularly for applications requiring real-time or near real-time responses. Latency can significantly impact the

effectiveness of IoT applications such as autonomous vehicles, healthcare monitoring, and industrial control systems. Delay optimization techniques aim to minimize communication and processing delays by optimizing data transmission paths, task scheduling, and resource allocation. These techniques include edge computing, where data processing is performed closer to the source rather than relying solely on centralized cloud servers. By reducing the distance data travels, edge computing significantly decreases latency and enhances system responsiveness. Additionally, intelligent routing protocols and priority-based scheduling further contribute to delay reduction by ensuring time-sensitive data is processed and transmitted promptly.

The integration of energy-aware scheduling, ECC-based authentication, and delay optimization creates a comprehensive framework for improving IoT system performance. These techniques complement each other in addressing the key challenges of heterogeneous environments. For instance, energy-aware scheduling ensures efficient resource utilization, while ECC-based authentication secures communication without imposing excessive computational burden. At the same time, delay optimization enhances the speed and reliability of data processing and transmission. Together, they create a balanced system that maintains efficiency, security, and responsiveness.

In practical implementations, this integrated approach supports scalable and flexible IoT architectures. As the number of connected devices increases, managing energy consumption, ensuring secure communication, and maintaining low latency become more complex. The combined use of these techniques enables systems to handle increased workloads while maintaining performance standards. For example, in smart healthcare systems, wearable devices continuously monitor patient data and transmit it to healthcare providers. Energy-aware scheduling ensures prolonged device operation, ECC-based authentication protects sensitive medical data, and delay optimization ensures timely delivery of critical information. Similarly, in industrial IoT environments, these techniques enhance operational efficiency, reduce downtime, and improve system reliability.

Moreover, advancements in artificial intelligence and machine learning further enhance the effectiveness of these techniques. Machine learning algorithms analyze usage patterns, predict energy consumption, and optimize scheduling decisions in real time. They also detect anomalies in authentication processes, strengthening security measures. In delay optimization, predictive models anticipate network congestion and adjust routing strategies accordingly. This intelligent

integration leads to more adaptive and self-optimizing IoT systems capable of operating efficiently in dynamic environments.

Despite their advantages, implementing these techniques presents certain challenges. Designing energy-aware scheduling algorithms that effectively balance performance and energy consumption requires careful consideration of device heterogeneity. Similarly, while ECC-based authentication is efficient, key management and distribution in large-scale IoT networks remain complex. Delay optimization techniques must also account for network variability and resource limitations. Addressing these challenges requires continuous research and innovation in algorithm design, network architecture, and system integration.

2. LITERATURE REVIEW

Kocot, Bartłomiej et al., (2023) High-performance computing (HPC), according to its name, is traditionally oriented toward performance, especially the execution time and scalability of the computations. However, due to the high cost and environmental issues, energy consumption has already become a very important factor that needs to be considered. The paper presents a survey of energy-aware scheduling methods used in a modern HPC environment, starting with the problem definition, tackling various goals set up for this challenge, including a bi-objective approach, power and energy constraints, and a pure energy solution, as well as metrics related to the subject. Then, considered types of HPC systems and related energy-saving mechanisms are described, from multicore-processors/graphical processing units (GPU) to more complex solutions, such as compute clusters supporting dynamic voltage and frequency scaling (DVFS), power capping, and other functionalities. The main section presents a collection of carefully selected algorithms, classified by the programming method, e.g., machine learning or fuzzy logic. Moreover, other surveys published on this subject are summarized and commented on, and finally, an overview of the current state-of-the-art with open problems and further research areas is presented.

Regonda, Nagaraju et al., (2022) Wireless sensor networks (WSNs) and the Internet of Things (IoT) are increasingly making an impact in a wide range of domain-specific applications. In IoT-integrated WSNs, nodes generally function with limited battery units and, hence, energy efficiency is considered as the main design challenge. For homogeneous WSNs, several routing techniques based on clusters are available, but only a few of them are focused on energy-efficient heterogeneous WSNs (HWSNs). However, security provisioning in end-to-end

communication is the main design challenge in HWSNs. This research work presents an energy optimizing secure routing scheme for IoT application in heterogeneous WSNs. In our proposed scheme, secure routing is established for confidential data of the IoT through sensor nodes with heterogeneous energy using the multipath link routing protocol (MLRP). After establishing the secure routing, the energy and network lifetime is improved using the hybrid-based TEEN (H-TEEN) protocol, which also has load balancing capacity. Furthermore, the data storage capacity is improved using the ubiquitous data storage protocol (U-DSP). This routing protocol has been implemented and compared with two other existing routing protocols, and it shows an improvement in performance parameters such as throughput, energy efficiency, end-to-end delay, network lifetime and data storage capacity.

Chen, Jinchao et al., (2022) Heterogeneous multiprocessor platform has been widely adopted as an effective approach to providing strong calculation capability while keeping complexity and energy consumption under control in large-scale systems. Although this platform is able to achieve efficient cost reduction and flexibility enhancement in the design and development process of real-time applications, it brings a serious and complex multi-task scheduling problem, especially for dependent tasks with energy consumption constraints. All tasks should be scheduled according to appropriate strategies such that their dependence requirements and energy consumption limitations would be satisfied even in the worst-case situations. In this work, we focus on the energy-aware scheduling problem of dependent tasks in heterogeneous multiprocessor systems. First, we model the dependent tasks and heterogeneous processors, and formulate the energy-aware scheduling problem as a constrained optimization one with an objective of minimizing the schedule length of tasks. Then, by adopting an efficient task prioritization strategy and a weight-based energy distribution strategy, we propose a list-based energy-aware scheduling algorithm to seek an approximate optimal start time and processor allocation for each task, guaranteeing that all tasks would be executed efficiently while meeting the dependence and energy requirements. Experiments with randomly generated tasks are conducted to evaluate the performances of the proposed approach in terms of schedule length, optimal solution ratio, and execution time.

Anbarasan, Helen & Natarajan, Jaisankar. (2022) Wireless body area networks (WBANs) are a research area that supports patients with healthcare monitoring. In WBAN, the Internet of Things (IoT) is connected with WBAN for a smart/remote healthcare monitoring system in which various medical diseases are diagnosed. Quality of service (QoS), security and energy

efficiency achievements are the major issues in the WBAN-IoT environment. Existing schemes for these three issues fail to achieve them since nodes are resource constrained and hence delay and the energy consumption is minimized. In this paper, a blockchain-assisted delay and energy aware healthcare monitoring (B-DEAH) system is presented in the WBAN-IoT environment. Both body sensors and environment sensors are deployed with dual sinks for emergency and periodical packet transmission. Various processes are involved in this paper, and each process is described as follows: Key registration for patients using an extended version of the PRESENT algorithm is proposed. Cluster formation and cluster head selection are implemented using spotted hyena optimizer. Then, cluster-based routing is established using the MOORA algorithm. For data transmission, the patient block agent (PBA) is deployed and authenticated using the four Q curve asymmetric algorithm. In PBA, three entities are used: classifier and queue manager, channel selector and security manager. Each entity is run by a special function, as packets are classified using two stream deep reinforcement learning (TS-DRL) into three classes: emergency, non-emergency and faulty data. Individual packets are put into a separate queue, which is called emergency, periodical and faulty. Each queue is handled using Reyni entropy. Periodical packets are forwarded by a separate channel without any interference using a multi objective based channel selection algorithm. Then, all packets are encrypted and forwarded to the sink nodes. Simulation is conducted using the OMNeT++ network simulator, in which diverse parameters are evaluated and compared with several existing works in terms of network throughput for periodic (41.75 Kbps) and emergency packets (42.5 Kbps); end-to-end delay for periodic (0.036 s) and emergency packets (0.028 s); packet loss rate (1.1%); residual energy in terms of simulation rounds based on periodic (0.039 J) and emergency packets (0.044 J) and in terms of simulation time based on periodic (8.35 J) and emergency packets (8.53 J); success rate for periodic (87.83%) and emergency packets (87.5%); authentication time (3.25 s); and reliability (87.83%).

Prerana, Nilesh & Khairnar, Prerana. (2022) The paper suggests the adaptation of the energy-efficient task assignment method in the case of a solar-powered network of IoT sensors with adaptive prediction algorithms. The classification of tasks as available or unavailable to energy resources uses Support Vector Machine (SVM), whereas Recursive Feature Elimination (RFE) is used to determine the best features to apply to the task scheduling process. The proposed treatment would integrate Python with machine learning framework (Scikit-learn) and real-time adaptive predictions (TensorFlow) so that the tasks scheduling mechanism drastically changes depending on the varying energy situation of solar energy. As was confirmed by the results, 15

percent of the improvement is revealed in the efficiency of the task completion and 25 percent decrease of the energy consumption with classification accuracy up to 92 percent. This approach also addresses the problem of traditional scheduling techniques in that it is easy to adapt, efficient, and scalable on large IoT networks. The study shows that machine learning and real-time energy analytics have a chance to transform the sustainability and efficiency of IoT systems powered by solar energy.

Deng, Zexi et al., (2020) As a technique to help achieve high performance in parallel and distributed heterogeneous computing systems, task scheduling has attracted considerable interest. In this paper, we propose an effective Cuckoo Search algorithm based on Gaussian random walk and Adaptive discovery probability which combined with a cost-to-time ratio Modification strategy (GACSM), to address task scheduling on heterogeneous multiprocessor systems using Dynamic Voltage and Frequency Scaling (DVFS). First, to overcome the shortcomings of poor performance in exploitation of the cuckoo search algorithm, we use chaos variables to initialize populations to maintain the population diversity, a Gaussian random walk strategy to balance the exploration and exploitation capabilities of the algorithm, and an adaptive discovery probability strategy to improve population diversity. Then, we apply the improved Cuckoo Search (CS) algorithm to assign tasks to resources, and a widely used downward rank heuristic strategy to find the corresponding scheduling sequence. Finally, we apply a cost-to-time ratio improvement strategy to further improve the performance of the improved CS algorithm. Extensive experiments are conducted to evaluate the effectiveness and efficiency of our method. The results validate our approach and show its superiority in comparison with the state-of-the-art methods.

Huang, Kai et al., (2020) Minimizing the schedule length of parallel applications, which run on a heterogeneous multi-core system and are subject to energy consumption constraints, has recently attracted much attention. The key point of this problem is the strategy to pre-allocate the energy consumption of unscheduled tasks. Previous articles used the minimum value, average value or a power consumption weight value as the pre-allocation energy consumption of tasks. However, they all ignored the different levels of tasks. The tasks in different task levels have different impact on the overall schedule length when they are allocated the same energy consumption. Considering the task levels, we designed a novel task energy consumption pre-allocation strategy that is conducive to minimizing the scheduling time and developed a novel task schedule algorithm based on it. After getting the preliminary scheduling results, we also

proposed a task execution frequency re-adjustment mechanism that can re-adjust the execution frequency of tasks, to further reduce the overall schedule length. We carried out a considerable number of experiments with practical parallel application models. The results of the experiments show that our method can reach better performance compared with the existing algorithms.

Abdel-Basset, Mohamed et al., (2020) The growth of Multiprocessing Systems (MPS) has become a necessity for dealing with complex tasks and speeding up their execution. Increasing the number of processing cores on a single chip produces a vast processing power, but the biggest obstacle is the energy generated from these cores. The traditional techniques guarantee to get the optimal schedule, but they are costly in terms of time and memory storage. In this paper, we propose an Improved Whale Algorithm (IWA) to allocate the dependent tasks in MPS with two objectives minimizing the energy consumption and the makespan. The processing cores are assumed to support Dynamic Voltage and Frequency Scaling (DVFS) as an effective technique to reduce energy. The allocation of tasks in MPS is an NP-hard problem. Inadequate scheduling of tasks can result in consuming energy. Also, the failure to complete the tasks before their predetermined deadlines is a critical issue for real-time applications. We consider three different sources of energy coming from the communication, idle, and active states of the processing cores. We use an initialization procedure to produce a population of candidate schedules that respects the precedence among tasks. In IWA, we employ two different discretization methods to map the continuous values into discrete ones. Two specialized crossover operations are adopted to boost the quality of the candidate schedules while respecting the dependencies among the tasks. IWA implements the Load Balancing Improvement (LBI) strategy to alleviate the load of tasks from heavy cores. LBI plays a vital role in decreasing the static energy consumption. We compare IWA with the other algorithms, and the results show the superiority of IWA.

Sarangi, Smruti et al., (2018) The Internet of Things (IoT) is poised to be one of the most disruptive technologies over the next decade. It is speculated, that we shall have billions of devices with communication capabilities very soon. Minimizing energy consumption is one of the most important problems in such IoT networks mainly because IoT nodes are distributed in the field with limited, unreliable, and intermittent sources of power. Even though the area of reducing power for stand-alone machines is very rich, there are very few references in the area of co-operative power minimization in a system with many IoT nodes. We propose two

algorithms in this paper, which are at the two ends of the spectrum: Local exchanges information between neighboring nodes, and Global uses a global server that has recent snapshots of the global state of the network. We show that both these algorithms reduce energy consumption by roughly 40% for settings that use data from real life IoT deployments (data from Barcelona city). We further show that if deadlines are tight, Local is preferable for smaller networks, and Global is preferable for larger networks. When deadlines are loose, Global is preferable if we need to follow hard real time semantics, otherwise Local is preferable.

Lago, Daniel et al., (2017) Ethernet is the main choice of connectivity in data centers operating in clouds. The Ethernet standards body (IEEE 802.3) has generated Ethernet specifications with increasing transmission rates since its inception. As a result, it is observed that data centers with groups of physical hosts having heterogeneous bandwidths. In this paper, we present an energy-aware virtual machine's scheduling method, taking into account this heterogeneity while aiming at energy efficiency. This method consists of two algorithms: one to determine to which physical hosts virtual machines should be allocated, and the other for the provision of bandwidth on physical hosts to virtual machines. Our study shows that, regarding energy savings for the studied scenarios, the presented method is comparable to other energy-aware methods in data centers with groups of machines with homogeneous settings, surpassing them in groups of machines with heterogeneous configurations, bringing improvements especially to data centers with heterogeneous bandwidths' networks or to where restrictive SLAs are used for the provision of bandwidth to virtual machines.

Akgun, Osman et al., (2014) We study a multiserver system where servers are heterogeneous in terms of both their speeds and their usage (energy) costs. We show that the optimal control policy is threshold type, and can be implemented in a decentralized manner through an individually optimal policy. When there are no arrivals, we also derive explicit expressions for the thresholds. We consider both the case with reassignment, where jobs can be moved from one server to another at any time, and the case where reassignment is not possible. When reassignment is possible, determining which server is preferred (i.e., the one that is used even if there are very few jobs waiting) is surprisingly difficult. With arrivals, for the reassignment and no-reassignment cases, determining server preference is also difficult, and depends on the arrival rate.

Mei, Jing et al., (2013) Efficient application scheduling is critical for achieving high performance in heterogeneous computing (HC) environments. Because of such importance,

there are many researches on this problem and various algorithms have been proposed. Duplication-based algorithms are one kind of well known algorithms to solve scheduling problems, which achieve high performance on minimizing the overall completion time (makespan) of applications. However, they pursuit of the shortest makespan overly by duplicating some tasks redundantly, which leads to a large amount of energy consumption and resource waste. With the growing advocacy for green computing systems, energy conservation has been an important issue and gained a particular interest. An existing technique to reduce energy consumption of an application is dynamic voltage/frequency scaling (DVFS), whose efficiency is affected by the overhead of time and energy caused by voltage scaling. In this paper, we propose a new energy-aware scheduling algorithm with reduced task duplication called Energy-Aware Scheduling by Minimizing Duplication (EAMD), which takes the energy consumption as well as the makespan of an application into consideration. It adopts a subtle energy-aware method to search and delete redundant task copies in the schedules generated by duplication-based algorithms, and it is easier to operate than DVFS, and produces no extra time and energy consumption. This algorithm not only consumes less energy but also maintains good performance in terms of makespan compared with duplication-based algorithms. Two kinds of DAGs, i.e., randomly generated graphs and two real-world application graphs, are tested in our experiments. Experimental results show that EAMD can save up to 15.59 % energy consumption for HLD and HCPFD, two classic duplication-based algorithms. Several factors affecting the performance are also analyzed in the paper.

3. OBJECTIVE (S) /NEED OF THE STUDY

1. To develop an energy-efficient scheduling technique that reduces power consumption between IoT devices and gateways.

2. To design a secure and lightweight authentication protocol using cryptographic methods for safe data transmission.

3. To introduce an energy-efficient and secure identity authentication scheme that ensures data privacy and minimizes energy usage.

4. To minimize communication delay in IoT devices using optimized queuing and clustering techniques.

5. To integrate energy efficiency, security, and delay reduction into a unified IoT framework for improved performance.

NEED OF THE STUDY

The need for the study on integrated energy-aware scheduling, ECC-based authentication, and delay optimization techniques for heterogeneous IoT systems will arise due to the rapid growth and increasing complexity of IoT environments. In the future, IoT systems will consist of a vast number of interconnected devices with diverse capabilities and resource constraints. This expansion will create challenges related to efficient energy utilization, secure communication, and timely data processing. Therefore, the study will be required to develop advanced strategies that will ensure optimal performance while maintaining system sustainability and reliability. Furthermore, the study will become essential as security threats and data breaches are expected to increase in IoT networks. ECC-based authentication will be explored to provide lightweight yet robust security solutions suitable for resource-constrained devices. At the same time, delay optimization techniques will be needed to support real-time applications such as healthcare monitoring and smart infrastructure. This study will contribute to the development of integrated frameworks that will address multiple challenges simultaneously, enabling scalable, efficient, and secure IoT systems in the future.

4. PROPOSED METHODOLOGY

The proposed methodology will adopt an integrated and multi-layered approach to address the key challenges of energy efficiency, secure authentication, and delay minimization in IoT

environments. Initially, an Energy-Efficient Scheduling (EES) algorithm with Interference Avoidance (IA) will be developed to optimize resource allocation and reduce energy consumption among heterogeneous IoT devices, including communication between devices and gateways.

To ensure secure communication, an authentication and key establishment mechanism based on Elliptic Curve Cryptography with Message Digest (ECCMD) will be implemented. This method will provide strong protection against common network attacks while maintaining lightweight cryptographic operations suitable for IoT devices. To further balance energy consumption and security requirements, an Energy-Efficient and Secure Identity Authentication (ESIA) technique will be introduced, which will minimize computational overhead while preserving data privacy and integrity.

For delay optimization, a hybrid approach will be proposed by combining M/G/1 queuing models with adaptive vacation policies and an energy-efficient clustering mechanism. This approach will dynamically manage network traffic, reduce queuing delays, and improve communication efficiency. The performance of the proposed framework will be evaluated through simulation, and it is expected that the results will demonstrate significant improvements in energy efficiency, security robustness, and delay reduction compared to existing methods.

5. EXPECTED OUTCOMES

The expected outcomes of the study on integrated energy-aware scheduling, ECC-based authentication, and delay optimization techniques for heterogeneous IoT systems will focus on improving overall system efficiency, security, and performance. The study will result in the development of advanced scheduling algorithms that will optimize energy consumption across diverse IoT devices. These algorithms will ensure that devices will utilize their power resources more effectively, thereby extending network lifetime and reducing operational costs. Additionally, the integration of intelligent mechanisms will enable dynamic adaptation to changing network conditions, leading to more sustainable IoT operations. Furthermore, the study will produce a secure authentication framework based on ECC that will enhance data protection and prevent unauthorized access in IoT environments. This will strengthen trust among connected devices and ensure safe communication across heterogeneous networks. The implementation of delay optimization techniques will also lead to reduced latency and improved response times, especially in real-time applications. Overall, the study will contribute to the

design of a comprehensive and scalable IoT framework that will support efficient, secure, and high-performance system operations in future technological environments.

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